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UNITED STATES DEPARTMENT OF AGRICULTURE
BULLETIN No. 1112

Washington, D. C. ▼ December 21, 1922

THE WESTERN YELLOW PINE MISTLETOE

EFFECT ON GROWTH AND SUGGESTIONS FOR CONTROL

By

CLARENCE F. KORSTIAN, Forest Examiner, Appalachian Forest Experiment Station, Forest Service, and W. H. LONG, Forest Pathologist, Office of Investigations in Forest Pathology, Bureau of Plant Industry

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INTRODUCTION.

Western yellow pine (*Pinus ponderosa* Laws.) occurs naturally from southern British Columbia to northern Mexico and from the Pacific coast to east of the one hundredth meridian. It is found in the forests of every State west of the Great Plains and in many of them it is one of the most important and valuable forest trees. In the Southwest, western yellow pine is by far the most important timber tree, constituting over 80 per cent of the commercial forests of Arizona and New Mexico, approximately 30 billion board feet.

During the past 12 years studies have been in progress to determine the effect of the mistletoe (*Razoumofskya cryptopoda* (Engelm.) Cov.) on the growth and seed production of western yellow pine. This parasite is the most widely distributed and one of the most

NOTE.—The author's names are in alphabetical order. The writers are indebted to Silviculturist G. A. Pearson, of the Fort Valley Experiment Station, for the permanent sample-plot data contained in Tables 11 and 17, for the data on the 1915 seed collection contained in Table 18, and for his general interest in the investigation.

serious enemies of the western yellow pine, and it has confronted the forester from the beginning of silvicultural practice in the Southwest. Especially on southern exposures and near the lower limit of the type, areas may be found on which fully 75 to 90 per cent of all the trees above 6 inches in diameter are infected with mistletoe.

In marking western yellow pine, there is often a question as to the advisability of cutting trees of various ages and degrees of mistletoe infection, or of allowing them to remain as seed trees and form a part of the future stand which will provide the basis for a subsequent cut. This problem involves not only a study of the effect of mistletoe on the rate of growth and the longevity of its host, but also of the effect of the parasitism on the amount and periodicity of seed production.

PHYSICAL AND CLIMATIC FEATURES OF THE REGION.

The areas in which the intensive studies were conducted lie within the Coconino and Tusayan National Forests on the Colorado Plateau, near the San Francisco Mountains in northern Arizona. The general topography of the plateau is rolling and consists of alternating flats comparatively free from rock and of rather low ridges which are very rocky. The underlying rock of the plateau consists principally of Coconino sandstone and Kaibab limestone overlaid by a lava flow of basalt and acidic volcanic rocks, mainly dacite, andesite, rhyolite, and latite, which constitute the main outcrops and surface rocks of the region. The soil varies widely from a fine sandy loam to a reddish friable clay, often containing an admixture of gravel and large volcanic bowlders. In the greater part of the region northeast of the San Francisco Mountains the soil is covered with black volcanic cinders to depths varying from one-half inch to about 18 inches. Mistletoe infection is rare on these cinder areas and where found at all is light. The level mesas and lower slopes of the plateau, ranging from approximately 6,500 to 8,500 feet in elevation, are covered with a forest, of which approximately 95 per cent is western yellow pine, constituting the most extensive forest of this species in North America.

The climate of that portion of the Colorado Plateau which is covered with a western yellow pine forest is indicated by the climatological data which have been secured at the Fort Valley Forest Experiment Station. Pearson's [1] studies in this locality, together with the records of the United States Weather Bureau throughout the region, have shown that the climate is characterized by marked seasonal variations in precipitation, atmospheric humidity, and

[1] Pearson, G. A. A Meteorological Study of Parks and Timbered Areas in the Western Yellow Pine Forests of Arizona and New Mexico. Monthly Weather Review, vol. 41: 1615–1629, 1914.

wind movement, and great daily ranges of atmospheric temperature. The amount of sunshine is unusually high. The mean annual precipitation in the western yellow pine forest amounts to between 20 and 25 inches, which occurs in two well-defined periods during July and August in the form of thundershowers and from November to April in the form of snow. The period from about April 15 to July 15 is characterized by desiccating southwest winds and excessive evaporation, which, together with the small amount of precipitation, produce conditions adverse to most types of vegetation. The high rate of evaporation, low atmospheric humidity, and high wind velocity very often cause excessive transpiration from plants. The climatic and soil conditions are such that nowhere within the western yellow pine type of the Southwest does this species make rapid growth.

The influence of such climatological conditions is generally considered unfavorable to the best development of the host and favorable to the distribution and growth of the parasitic mistletoe. Weir [2] has emphasized the fact that the ecological relationships of the mistletoes, although they are parasitic, are similar to those of other cholorphyllaceous plants in that they also respond to light, gravity, and certain chemical stimuli, while the marked variations in temperature to which the host readily responds are only slightly effective on the parasite. The low atmospheric humidity has a very slight influence on the xerophytic mistletoe, while the great amount of sunshine is favorable to the parasite. The unusually high winds of the Southwest frequently cause rather serious losses to western yellow pine stands in exposed situations through windfall, and the wind is known to aid in the dissemination of the mistletoe seed from tree to tree.

It follows that, where a virulent parasite responds favorably to its habitat, the host will rapidly deteriorate on the more unfavorable sites. From numerous observations made in various parts of the Southwest, it is apparent that a rather definite relation exists between the unfavorableness of the site and the degree of mistletoe infection. The percentage of infection and the resulting mortality of the host is usually higher on exposed dry ridges and south slopes than on the more favorable sites. This condition is very apparent on the Santa Fe National Forest in northern New Mexico.

THE WESTERN YELLOW PINE MISTLETOE.

The family Loranthaceæ has two genera in the United States, Phoradendron and Razoumofskya. The species of Phoradendron are parasitic on both hardwoods and conifers, but mainly on hard-

[2] Weir, James R. The Larch Mistletoe: Some Economic Considerations of Its Injurious Effects. U. S. Dept. of Agri. Bul. 317, pp. 5-10, 1916.

woods, while the genus Razoumofskya is found exclusively on conifers. Several species of the latter genus are rather common in the western United States and in some localities have become very serious parasites. *Razoumofskya cryptopoda*, the western yellow pine mistletoe, is one of the most widely distributed of all the species, usually being found wherever the western yellow pine grows. (Pl. I, Fig. 1.)

Razoumofskya cryptopoda flowers in Arizona and New Mexico during April and May, and the fruit matures in August and September of the next year. When the seeds begin to ripen, the berries gradually turn downward on their pedicels until the base of each berry when fully mature points upward. The gelatinous seeds when ripe are suddenly and forcibly ejected upward to a distance of several yards by the giving way of a ring of tissue situated near the base of the berry. This method of seed dissemination is common to all species of Razoumofskya. Experiments and extended observations indicate that the aerial portions of both staminate and pistillate plants die and fall from the trees after one season of flowering and fruiting. (Pl. I, Fig. 2.)

EFFECT OF MISTLETOE ON GROWTH OF HOST.

The study of the effect of mistletoe on its host was accomplished (1) by periodic measurements and observations of standing trees, both infected and healthy; and (2) by detailed growth studies and observations of infected and healthy felled trees.

EFFECT ON BOLE OF TREE.

Ninety-one healthy and mistletoe-infected trees between 10 and 30 inches in diameter breast high on three different areas within a radius of 5 miles of the Fort Valley Experiment Station were tagged, numbered, measured, and mapped in 1910 with the object of determining the effect of mistletoe on the diameter and height-growth of the host, the diameter growth of limbs, and the growth of the merchantable contents of the bole. The diameters were measured with a diameter tape at 1, 4.5, 17, and 33 feet above the ground. The total heights were measured with a Forest Service standard hypsometer. The diameters of 20 healthy and 34 mistletoe-infected limbs falling in different infection classes were measured on 18 standing trees with a view of determining the effect of mistletoe on the growth of limbs. The points of measurement at 6 inches from the bole of the tree and every 6 inches beyond this point were marked by driving a 6-penny copper nail into the wood. All of the trees were remeasured in 1915 and were reclassified into four degrees of mistletoe infection, according to the prevalence of mistletoe on the tree, as follows: O, healthy trees without mistletoe; X, light

FIG. 1.—A typical mistletoe colony on western yellow pine. The stems of dead and dying mistletoe plants are in the center and the youngest plants are seen at each end of the lesion.

FIG. 2.—Advance of a mistletoe lesion on a twig of western yellow pine; dead stems of early infection in the center and young, vigorous mistletoe plants at the upper edge of the lesion.

mistletoe infection; XX, medium mistletoe infection; XXX, heavy mistletoe infection.

In order to check any material effect that the different crown classes might have on the rate of growth the trees were also classified, according to their dominance or relative position in the crown canopy of the group, into the following crown classes:

Isolated.—Trees growing in the open which do not form a contiguous part of the regular group canopy.

Dominant.—Trees with crowns extending above the general level of the group canopy and receiving full light from above and partly from the side; larger than the average trees in the group, and with crowns well developed but possibly somewhat crowded.

Codominant.—Trees with crowns forming the general level of the group canopy and receiving full light from above, but comparatively little from the sides; usually with medium-sized crowns more or less crowded on the sides.

Intermediate.—Trees with crowns below, but still extending into the general level of the group canopy, receiving a little direct light from above but none from the sides, usually with small crowns considerably crowded on the sides.

Suppressed.—Trees with crowns below the general level of the group canopy and receiving no direct light either from above or from the sides; usually with small, poorly developed crowns.

There are two well-recognized forms of *Pinus ponderosa*, "black jack" and "yellow pine," based on age, rate of growth, and the resulting color of the bark. The term "black jack" applies to the young, vigorous trees under 125 to 150 years old which are characterized by a dark, almost black, or dark brown, narrow-furrowed bark. The "yellow pine" form comprises the older trees, which are characterized by a yellowish or reddish brown, widely furrowed bark. There is a marked difference in the form and volume of black jacks and yellow pines. The average black jack has a greater taper, a more rapid rate of growth, and approximately 10 per cent smaller cubic volume than the average yellow pine of the same diameter and height, which were the chief reasons for the segregation of black jacks and yellow pines.

The mean diameter growth or accretion of the standing black jacks for the 5-year period from 1910 to 1915, grouped according to degree of mistletoe infection, is shown in Table 1. The diameters were averaged by infection classes for each year mentioned, and the difference was computed as the growth during the 5-year period or the periodic accretion. The average growth per year during the period considered is termed the periodic annual accretion. The data show an almost consistent decrease in the diameter growth of black jack with the degree of mistletoe infection. The slight inconsistency exhibited in the rate of diameter growth of the *o* and *x* infection

classes might be explained by the fact that of the 27 trees in the infection class, 11 per cent were isolated trees which did not form a part of the forest canopy, 28 per cent were dominant, 57 per cent were codominant, and 4 per cent were intermediate trees, while with the *x* infection class 60 per cent were isolated trees which did not form a part of the forest canopy and 40 per cent were in the codominant crown class. Table 2 consistently shows a decrease in the rate of diameter growth of yellow pine which varies directly with the degree of mistletoe infection.

TABLE 1.—*Comparison of the average diameter growth or accretion of 58 standing black jacks, for a 5-year period, grouped according to degree of mistletoe infection.*

Degree of infection.	Diameter breast-high.		Accretion, 1910–1915.		Basis.
	1910	1915	Periodic.	Periodic Annual.	
	Inches.	*Inches.*	*Inches.*	*Inch.*	*Trees.*
0	16.16	16.97	0.81	0.16	27
x	17.65	18.63	.98	.20	6
xx	15.82	16.57	.75	.15	15
xxx	14.24	14.36	.12	.02	10

TABLE 2.—*Comparison of the average diameter growth or accretion of 33 standing yellow pines, for a 5-year period, grouped according to degree of mistletoe infection.*

Degree of infection.	Diameter breast-high.		Accretion, 1910–1915.		Basis.
	1910	1915	Periodic.	Periodic annual.	
	Inches.	*Inches.*	*Inch.*	*Inch.*	*Trees.*
0	24.60	25.30	0.70	0.14	9
x	25.56	26.04	.48	.10	8
xx	22.14	22.44	.30	.06	7
xxx	21.49	21.61	.12	.02	[1] 9

[1] Five trees of this class died during the 5-year period and were not included in the computation.

TABLE 3.—*Comparison of total volume growth or increment of 58 standing black jacks, for a 5-year period, grouped according to degree of mistletoe infection.*

Degree of infection.	Total volume.		Increment, 1910–1915.			Basis.
	1910	1915	Periodic.	Periodic annual.		
	Cubic feet.	*Cubic feet.*	*Cubic feet.*	*Cubic feet.*	*Per cent.*	*Trees.*
0	987.2	1,100.9	113.7	22.7	2.30	27
x	291.4	324.4	33.0	6.6	2.26	6
xx	434.0	470.6	36.6	7.3	1.68	15
xxx	234.9	243.2	8.3	1.7	.72	10

TABLE 4.—*Comparison of the total volume growth or increment of 33 standing yellow pines, for a 5-year period, grouped according to degree of mistletoe infection.*

Degree of infection.	Total volume.		Increment, 1910–1915.			Basis.
	1910	1915	Periodic.	Periodic annual.		
	Cubic feet.	*Cubic feet.*	*Cubic feet.*	*Cubic feet.*	*Per cent.*	*Trees.*
o	1,151.0	1,226.0	75.0	15.0	1.30	9
x	1,206.0	1,250.0	44.0	8.8	.73	8
xx	706.0	725.0	19.0	3.8	.54	7
xxx	801.0	809.0	8.0	1.6	.20	[1]9

[1] Five trees of this class died during the 5-year period and were not included in the computation.

Table 3 shows the total volume growth or increment of the standing black jacks for the same 5-year period, grouped by infection classes. The total volumes were computed by applying a volume table based on diameter and total height to the dimensions of each tree as measured in 1910 and 1915. It was found from taper measurements that volume tables could safely be applied to the individual trees. The volumes of all trees were totaled by infection classes. The difference between the total volumes at each time of measurement represents the periodic increment, and the average volume growth per year during the period considered is the periodic annual increment. Table 4 shows the increment of the standing yellow pines for the same 5-year period. Both forms of western yellow pine exhibit a consistent decrease in the increment of those trees which are infected with mistletoe varying directly with the degree of infection.

Bole measurements were made at 16-foot intervals to insure greater accuracy in the study of the effect of mistletoe on the growth of the merchantable contents of the bole of the tree. Table 5 gives a comparison of the diameter growth of the bole of 33 trees at 4.5, 17, and 33 feet above the ground. The comparative increments of the same trees are shown in Table 6. The apparent discrepancy between the rate of growth of the uninfected and lightly infected classes, as was noted above, is apparently due either to the varying proportions of the trees among the different crown classes or it may be possible that the infection at first results in a slight stimulation of the tree. In computing the volume, each section below the highest point of measurement was cubed as a cylinder by averaging the basal areas of the ends and multiplying by the length of the section;[2] that portion above was considered as the top of the tree and its volume was computed as that of a cone.

The growth of the standing trees was further checked by complete stem analysis of 102 felled trees. Sections were examined as near to the surface of the ground as possible, at 4.5 feet above the ground,

[2] This is known as the Smalian method. See Graves, Henry S., Forest Mensuration, pp. 91–93. New York, 1907.

and at every 8 feet above this point. The measurements were recorded by 5-year periods instead of by decades, as is the usual practice in complete stem analysis. The trees were selected as nearly as possible from the same site, kind of stand, and the same age and crown classes. Only those trees free from abnormalities or other possible causes of deterioration or conditions deterrent to their growth were studied, thus permitting only two variables to enter into the results, the age of the tree and the degree of mistletoe infection. The classification of the tree according to degree of infection represents the consensus of opinion of three different observers.

The basic data for each of the individual felled trees which were analyzed to show the effect of mistletoe on the growth and seed production of western yellow pine have been arranged in Table 7, according to the age of the trees. In compiling the stem analyses the data for each tree were computed separately. The diameters and heights of each tree for each fifth year, dating back from the year of analysis, were correlated with age in growth-analysis diagrams, from which the dimensions of each tree for each integral 5 years of age or quinquennium were read.

TABLE 5.—*Comparison of the average diameter growth or accretion of 33 standing black jacks, for a 5-year period, at 4.5, 17, and 33 feet from ground, grouped according to degree of mistletoe infection.*

Degree of infection.	Diameter outside bark.						Accretion, 1911–1916.						Basis.
	1911			1916			Periodic.			Periodic annual.			
	4.5 feet.	17 feet.	33 feet.	4.5 feet.	17 feet.	33 feet.	4.5 feet.	17 feet.	33 feet.	4.5 feet.	17 feet.	33 feet.	
	In.	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*Trees.*
0	17.93	15.28	12.69	19.03	16.30	13.71	1.10	1.02	1.02	0.22	0.20	0.20	16
x	22.25	19.59	14.14	23.40	20.85	15.25	1.15	1.26	1.11	.23	.25	.22	4
xx	15.92	13.20	8.65	16.78	13.81	9.46	.86	.61	.81	.17	.12	.16	7
xxx	16.47	14.42	9.19	17.15	14.64	9.31	.68	.22	.12	.14	.04	.02	6

TABLE 6.—*Comparison of the total volume growth or increment of 33 standing black jacks, for a 5-year period, grouped according to degree of mistletoe infection.*

Degree of infection.	Total volume.		Increment, 1911–1916.			Basis.
	1911	1916	Periodic.	Periodic annual.		
	Cubic feet.	*Cubic feet.*	*Cubic feet.*	*Cubic feet.*	*Per cent.*	*Trees.*
0	919.76	1,047.40	127.64	25.53	2.78	16
x	359.07	410.65	51.58	10.32	2.87	4
xx	286.83	316.08	29.25	5.85	2.04	7
xxx	262.65	273.97	11.32	2.26	.86	6

TABLE 7.—*Basic data for 107 felled trees showing the effect of mistletoe on the growth and seed production of western yellow pine.*

Tree number.	Age.	Diameter breast high.	Diameter growth for last 5 years.	Total height.	Height growth for last 5 years.	Total volume.	Volume growth for last 5 years.	Degree of infection.[1]	Crown class.[2]	Average length of leaves.	Average length of leaf tufts.	Seed crop, 1915.[3]
	Years.	*Inch.*	*Inch.*	*Feet.*	*Feet.*	*Cu. ft.*	*Cu. ft.*			*Inch.*	*Inch.*	
58	23	4.0	1.5	15.5	4.5	1.81	0.39	o	X	5.5	19.3	O
75	23	4.6	1.6	14.5	3.0	.84	.55	x	C	4.1	7.0	O
59	24	2.8	.7	13.5	3.5	.27	.08	o	C	5.6	19.3	O
74	24	3.2	1.0	13.5	3.5	.36	.17	o	C	5.1	11.6	O
67	25	1.9	.4	9.0	1.0	.11	.03	xx	C	2.6	5.0	O
62	26	2.4	.6	13.5	3.0	.22	.11	o	C	4.0	9.6	O
70	26	2.0	1.0	11.5	3.5	.12	.06	o	D	5.1	8.0	O
85	27	.....	.....	3.1	.5	.01	.001	xxx	X	3.0	3.2	O
72	28	2.4	1.2	11.5	4.0	.19	.09	o	D	6.0	10.3	O
73	28	6.2	1.8	24.5	4.5	2.02	.99	o	C	5.8	11.3	O
86	28	.....	.....	3.2	.8	.021	.014	xxx	X	3.6	5.3	O
84	29	.....	.....	2.8	.3	.009	.001	xxx	X	2.8	3.4	O
60	30	5.4	.6	23.5	3.0	1.58	.47	x	D	4.1	10.0	O
69	30	1.9	.4	9.5	2.0	.09	.01	x	I	3.3	4.3	O
71	30	5.4	1.6	17.5	4.0	.88	.32	o	C	5.6	11.3	O
22	30	4.8	1.8	17.5	4.5	.98	.53	o	D	5.6	23.3	O
65	31	4.6	1.0	17.5	3.0	.80	.29	x	C	4.1	8.6	O
15	31	.....	.....	3.5	1.0	.07	.06	x	X	3.8	9.3	O
68	32	3.5	.2	10.5	1.0	.41	.13	xx	X	2.1	3.3	O
17	33	.....	.....	3.0	.5	.01	.002	xx	X	.....	.....	O
61	33	4.8	.5	16.0	1.5	1.06	.27	xxx	C	2.7	5.5	O
64	33	3.0	.5	13.5	2.0	.33	.13	xx	I	3.3	10.3	O
63	35	.5	.2	5.5	.5	.09	.02	xxx	I	2.3	3.0	O
66	35	4.0	1.2	17.5	3.5	1.03	.42	x	C	4.1	8.6	O
83	37	.....	.....	4.3	.7	.014	.002	xxx	X	3.1	2.8	O
107	37	7.1	.....	21.0	.....	2.40	.....	o	D	5.2	8.5	O
18	39	5.1	1.1	18.0	3.0	1.78	.69	o	X	5.3	13.0	O
20	46	6.2	1.1	17.5	2.0	1.85	.63	xx	X	3.7	4.7	O
19	53	6.2	.8	27.0	3.0	3.11	1.03	x	X	5.6	17.9	O
29	60	15.6	1.5	47.5	3.5	21.24	5.05	o	X	6.8	13.3	O
47	65	13.2	1.6	51.5	5.0	19.79	4.69	o	C	5.3	8.0	L
81	65	10.8	1.3	46.0	4.5	11.22	3.38	o	C	5.8	22.3	O
82	65	9.0	.4	33.0	1.5	5.09	.76	xxx	C	4.1	6.6	O
52	66	11.2	.4	30.5	.5	8.14	.99	xx	X	3.5	5.0	O
89	66	7.9	.7	33.5	2.5	3.35	.72	x	X	4.6	7.7	O
48	69	10.8	1.1	39.0	2.5	9.09	2.11	xx	C	4.5	6.0	O
57	70	15.8	2.0	60.0	5.0	27.38	6.12	o	C	6.3	7.3	L
80	70	8.8	1.0	37.5	1.5	5.63	.94	o	S	6.6	7.5	O
88	71	7.5	.6	34.5	1.5	4.29	.47	x	C	4.3	6.7	O
8	72	4.4	.3	17.0	1.0	.85	.11	xx	I	5.6	.....	O
46	72	15.6	1.1	43.5	3.0	19.84	3.59	o	X	5.1	10.6	O
37	74	7.0	.1	20.0	1.0	1.66	.08	xxx	X	3.5	3.1	O
21	75	7.4	.4	30.0	.5	3.77	.49	xxx	X	2.6	2.5	O
98	76	19.5	1.5	60.5	3.5	40.70	4.79	o	C	5.0	6.7	O
10	78	11.8	.4	36.5	.5	10.17	.67	xx	X	4.5	.....	.....
77	78	11.7	.5	38.5	.5	10.68	1.08	xxx	X	3.6	5.3	O
49	79	9.5	.3	32.5	1.0	5.47	.53	xxx	C	4.0	4.6	O
78	79	5.4	.4	26.0	1.0	2.08	.43	xx	S	3.5	4.3	O
104	79	14.5	.....	42.0	.....	19.00	.....	o	X	3.8	6.2	L
1	80	12.6	.2	39.5	.7	14.60	1.13	xxx	X	.....	.....	O
11	80	10.8	1.5	34.5	3.5	7.82	2.21	o	X	6.3	18.0	O
103	80	7.5	.....	20.0	.....	2.50	.....	xxx	X	2.8	4.2	O
5	82	8.0	.4	33.5	.5	5.91	.33	xxx	C	.....	.....	O
9	82	10.6	.2	44.5	.5	9.64	.43	xx	X	3.3	.....	O
44	82	11.2	.6	39.0	2.5	9.07	1.56	x	C	4.3	5.0	O
90	82	6.9	.3	28.5	.5	2.46	.36	x	C	4.3	5.3	O
6	83	10.8	1.5	47.5	4.0	10.67	2.76	o	D	5.8	.....	O
38	83	9.8	.2	37.5	.2	7.65	.30	xxx	X	3.3	5.0	O
105	83	8.1	.....	26.0	.....	3.55	.....	xxx	C	3.5	4.2	O
106	83	15.2	.....	49.0	.....	22.50	.....	o	C	5.5	6.1	L
54	84	7.1	.5	27.5	2.0	2.51	.37	xxx	C	4.3	4.6	O
43	85	8.2	.3	40.5	2.5	6.65	1.23	xx	C	4.1	5.0	O
51	85	14.4	1.2	47.5	3.0	21.19	3.62	o	C	5.6	8.0	O
24	87	11.1	1.6	41.5	4.0	10.93	2.84	o	X	6.0	22.0	O
79	88	5.8	.4	24.5	.5	1.87	.23	xxx	S	4.1	5.6	O
14	89	10.4	.5	35.5	2.0	7.84	.98	xxx	D	3.6	5.7	.....
53	92	14.0	1.1	46.5	2.5	16.00	2.69	o	C	5.6	8.6	L
13	93	7.8	.2	32.5	.5	4.26	.27	xx	X	5.1	7.8	O

[1] Degree of infection classified as follows: o = healthy trees without mistletoe, x = light mistletoe infection, xx = medium mistletoe infection, xxx = heavy mistletoe infection.

[2] Crown class of trees classified as follows: X = isolated, D = dominant, C = codominant, I = intermediate, S = suppressed.

[3] Seed crop classified as follows: H = heavy, G = good, M = medium, L = light, O = none.

TABLE 7.—*Basic data for 107 felled trees showing the effect of mistletoe on the growth and seed production of western yellow pine*—Continued.

Tree number.	Age.	Diameter breast high.	Diameter growth for last 5 years.	Total height.	Height growth for last 5 years.	Total volume.	Volume growth for last 5 years.	Degree of infection.	Crown class.	Average length of leaves.	Average length of leaf tufts.	Seed crop, 1915.
	Years.	*Inch.*	*Inch.*	*Feet.*	*Feet.*	*Cu. ft.*	*Cu. ft.*			*Inch.*	*Inch.*	
23	93	6.8	0.1	22.5	1.0	2.30	1.80	xxx	C	3.1	3.3	O
91	93	8.9	.4	36.0	1.0	5.65	1.01	x	X	4.5	6.5	O
2	94	12.0	1.5	40.5	1.0	15.18	4.40	o	X	.....	.....	O
42	94	14.8	.2	41.5	.5	20.03	.67	xxx	X	4.5	5.6	O
76	94	9.8	.7	39.0	1.0	7.80	.77	xxx	C	3.1	4.6	O
7	95	4.0	.1	21.0	1.0	.84	.16	xxx	S	4.1	.....	O
56	95	14.4	.3	42.5	1.0	16.37	.42	xxx	C	4.0	5.0	O
87	97	9.0	.5	43.0	1.0	7.06	.85	x	C	4.6	5.3	O
28	98	18.1	1.5	64.5	6.0	47.49	6.48	x	X	6.3	11.3	O
25	100	8.3	.2	30.0	.5	4.23	.28	xxx	D	4.5	3.6	O
55	100	14.6	.2	49.5	1.0	20.05	1.08	xxx	C	5.2	5.5	O
99	102	20.6	1.0	64.5	3.0	52.44	6.81	o	C	4.7	6.3	O
12	104	12.4	.5	41.5	1.5	13.13	1.17	o	X	5.3	6.1	O
93	104	21.6	1.1	73.0	3.5	63.47	5.73	o	C	4.8	5.7	L
95	105	20.4	.6	60.5	1.5	62.11	4.30	x	C	5.2	7.2	O
40	106	9.4	.8	53.0	3.0	8.62	.92	xx	C	5.3	6.6	O
39	112	11.6	1.2	62.0	3.5	18.82	5.59	o	C	5.0	10.6	O
96	114	18.8	.6	70.5	1.0	43.68	1.64	xx	C	4.3	6.8	O
94	117	20.4	1.0	78.0	3.0	69.85	5.05	o	C	5.1	6.2	L
45	120	19.4	.4	67.0	1.0	42.59	1.32	xx	C	4.3	3.6	O
97	120	22.4	1.7	79.5	2.5	83.56	11.32	o	C	5.4	6.8	L
41	121	11.9	.8	58.0	1.0	16.10	1.09	xxx	C	5.3	6.6	O
27	123	17.6	.1	46.5	.5	21.86	.58	xxx	X	4.6	5.1	O
4	124	20.2	1.7	68.5	1.0	67.68	9.40	o	X	6.0	9.0	O
92	125	17.1	.4	68.0	1.0	43.33	3.75	xx	C	5.1	5.0	O
3	126	20.3	.3	55.5	.3	42.03	1.49	xxx	X	4.0	2.5	O
50	130	23.4	2.3	79.5	1.5	92.78	8.56	o	D	5.0	8.3	M
26	134	18.2	.2	45.0	.5	25.23	.82	xxx	D	3.6	2.5	O
16	138	20.2	.4	59.5	.5	50.01	3.74	x	X	5.1	11.5	O
36	214	19.2	1.2	67.5	1.5	44.90	4.27	o	C	5.6	7.1	L
102	214	23.0	1.4	85.0	1.0	108.80	7.98	o	D	5.5	5.3	M
33	217	15.2	.5	58.5	1.0	32.92	2.62	xxx	X	4.7	8.3	L
30	218	18.2	.4	78.5	.2	59.68	2.55	xxx	C	3.5	.....	O
100	218	20.8	.5	77.5	1.5	71.92	2.63	o	C	5.3	5.2	O
101	218	25.6	1.3	87.5	1.0	133.67	10.17	o	X	4.8	5.8	L
31	220	16.0	.1	84.5	.3	54.91	1.15	xxx	C	5.0	7.1	O
32	220	21.6	.8	87.5	1.0	90.26	7.06	o	D	5.8	7.3	M
34	230	25.6	.4	76.5	.3	107.47	2.88	xxx	X	5.2	8.8	O
35	233	17.6	.2	72.0	.5	65.10	5.68	xxx	C	4.5	5.6	O

Figure 1 shows the graphic growth analysis diagram for tree No. 4, a typical healthy western yellow pine, while Figure 2 shows the same kind of a diagram for tree No. 27, which was heavily infected with mistletoe. Both trees grew within a short distance of each other on the same site; they were of practically the same age and both belonged to the isolated crown class and the 101 to 140 year age class; therefore these factors can not be held accountable for the material falling off in the increment of the heavily infected tree. The very marked decrease in the rate of growth during the last 30 years, evidently due to the parasitism of the mistletoe, is very clearly shown by the closeness of the last seven quinquennial lines near the outside of the cone in Figure 2, which represents the growth of tree No. 27.

A set of curves was drawn for each tree showing the relation of age to diameter breast high, total height, and volume. This curving eliminated the irregularities and irrelevant abnormalities occurring in each tree. The data for the individual trees were then averaged by a series of harmonized curves for each infection and 40-year age

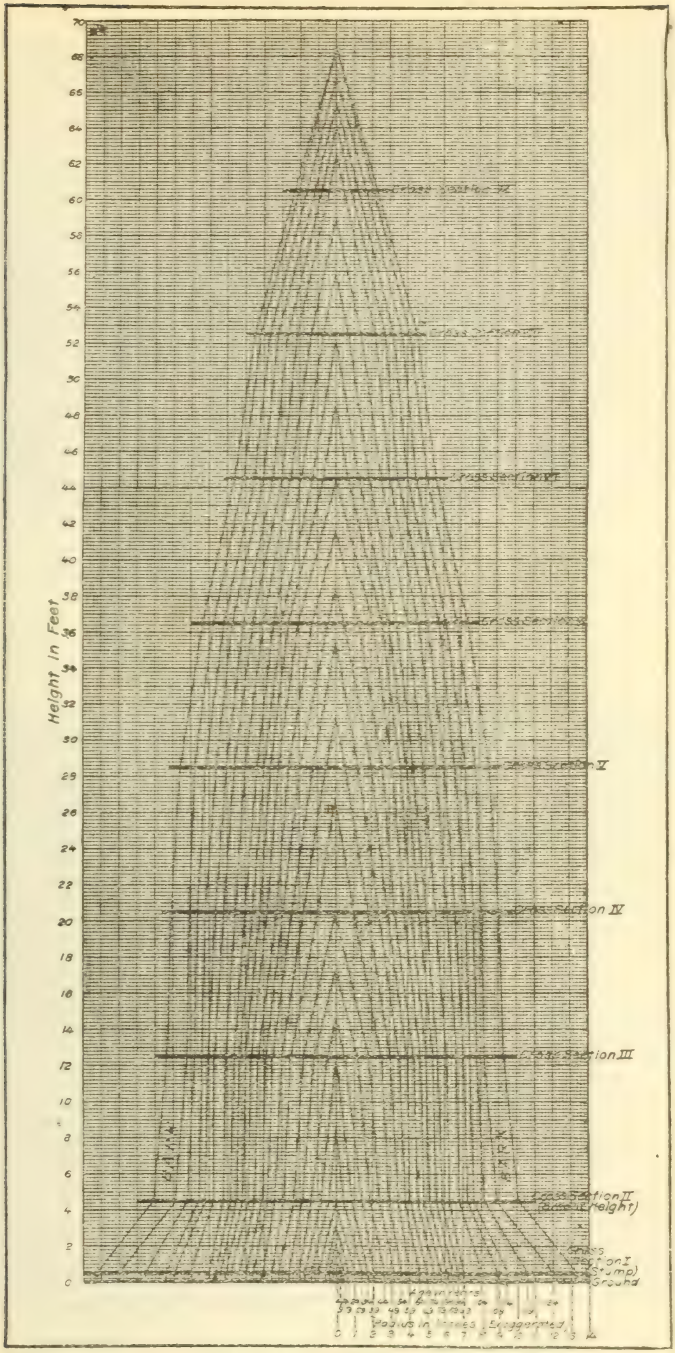
Height in Feet
Cross Section VI
Cross Section V
Cross Section IV
Cross Section III
Cross Section II (at base of height)
Cross Section I (at stump) Ground
Radius in Inches Diagrammed

FIG. 1.—Graphic representation of the growth analysis of felled tree No. 4, a sound healthy western yellow pine. (Height greatly reduced in porportion to diameter.)

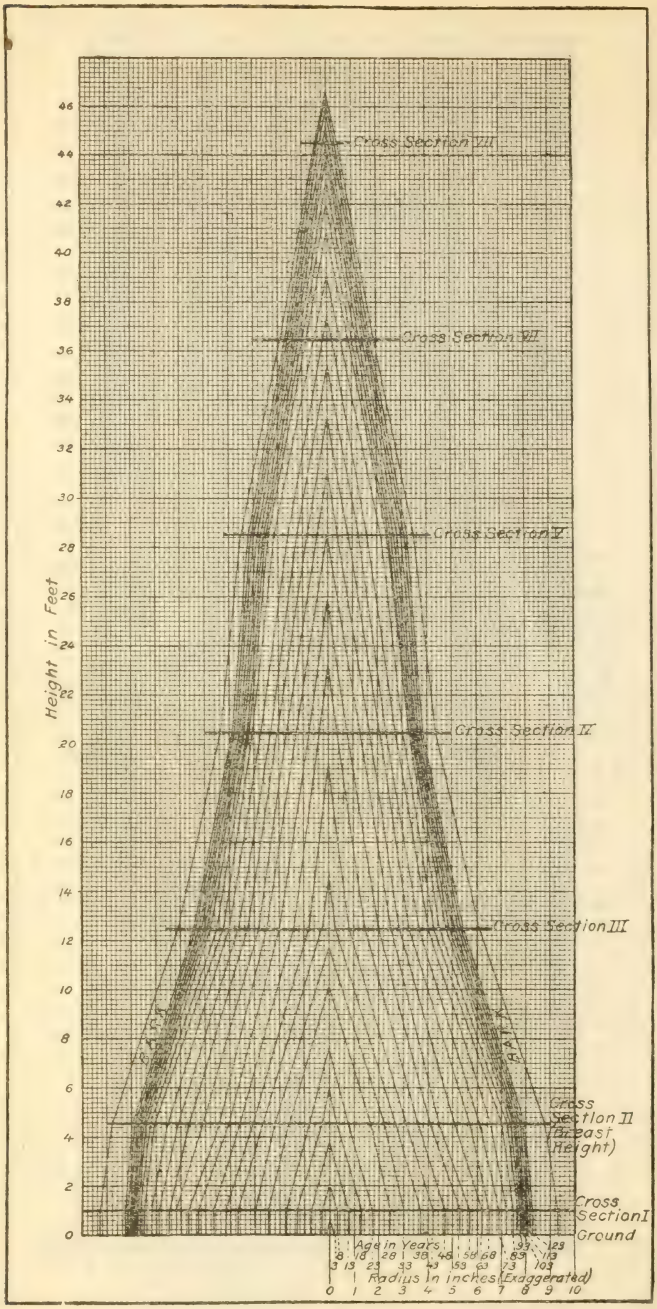

FIG. 2.—Graphic representation of the growth analysis of felled tree No. 27, a western yellow pine heavily infected with mistletoe. (Height greatly reduced in proportion to diameter.)

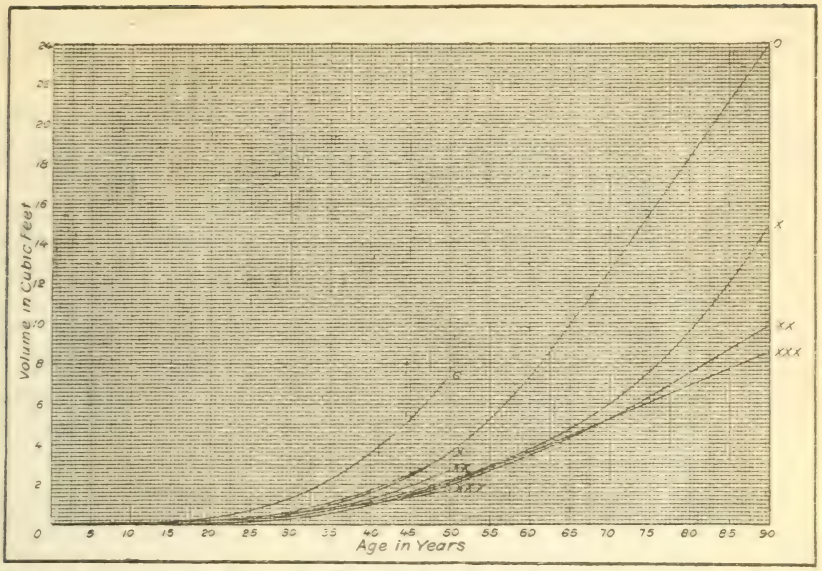

FIG. 3.—Volume-age curves showing the effect of the four degrees of mistletoe infection on the 21-60 and 61-100 year age classes.

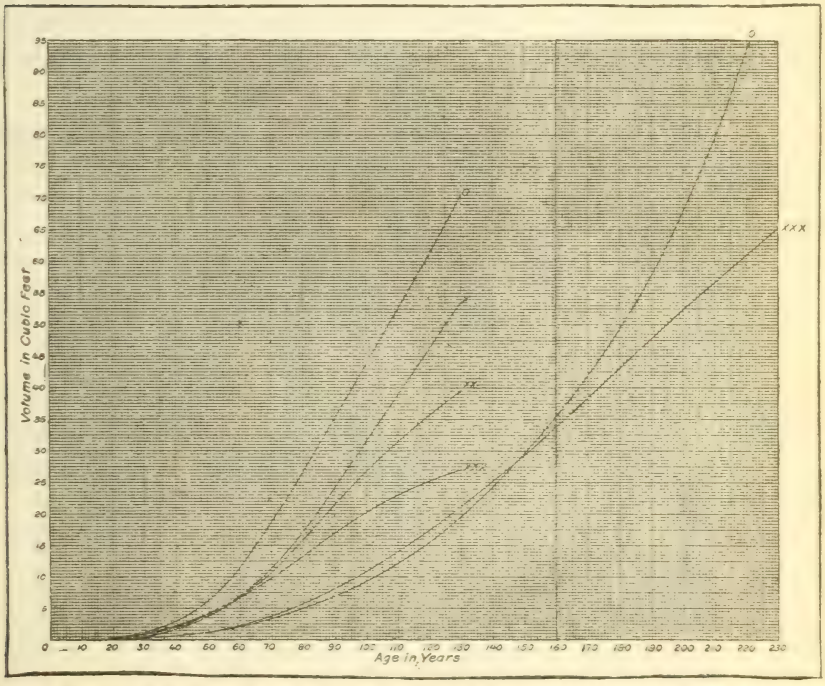

FIG. 4.—Volume-age curves showing the effect of the different degrees of mistletoe infection on the 101-140 and the 201-240 year age classes.

class. Forty-year age classes were used instead of the usual 20-year age classes, because they provided a greater number of trees as the basis for each age and infection class.

The harmonized volume-age curves for the 21 to 60 and the 61 to 100 year age classes are shown in Figure 3, which indicates that the mistletoe infection was sufficiently severe to retard the rate of growth of the more heavily infected trees of these two age classes by approximately 20 years. Figure 4 shows a similar retardation of the increment for the 101 to 140 and the 201 to 240 year age classes, except that the rate of growth of the more heavily infected trees of these age classes has been on the decline for the past 70 to 80 years. The curves in both figures show conclusively that the current increment is directly dependent upon the degree of mistletoe infection. Generally speaking, the degree of mistletoe infection increases with the length of time which a tree has been infected.

A further comparison of the average diameter growth or accretion of the felled western yellow pine trees for the 25-year period from 1890 to 1915, grouped by 40-year age classes and degree of mistletoe infection, is shown in Table 8. A similar comparison of the average height growth or accretion of the same trees is given in Table 9. Table 10 shows a comparison of the average volume growth or increment of the same trees for the same period, similarly grouped by age and infection classes. The 21 to 60, 61 to 100, and the 101 to 140 year age classes in Tables 8, 9, and 10 are composed entirely of black jacks, while yellow pines constitute the 201 to 240 year age class.

TABLE 8.—*Comparison of the average diameter growth or accretion of 102 felled western yellow pine trees, for a 25-year period, grouped by age classes and degree of mistletoe infection.*

Age class.	Degree of infection.	Diameter breast high..		Accretion, 1890–1895, periodic annual.	Diameter breast high, 1900.	Accretion, 1895–1900, periodic annual.	Diameter breast high, 1905.	Accretion, 1900–1905, periodic annual.	Diameter breast high, 1910.	Accretion, 1905–1910, periodic annual.	Diameter breast high, 1915.	Accretion, 1910–1915, periodic annual.	Basis.
		1890	1895										
Years.		*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*Trees.*
21 to 60.....	o	0.8	1.0	0.04	1.6	0.12	2.3	0.14	3.7	0.28	5.0	0.26	11
	x	.2	.6	.08	1.4	.16	2.5	.22	3.5	.20	4.4	.18	6
	xx	.1	.4	.06	.8	.08	1.3	.10	1.8	.10	2.1	.06	7
	xxx	.....	.3	.06	.6	.06	.7	.02	.9	.04	1.1	.04	5
61 to 100....	o	7.2	8.2	.20	9.3	.22	10.4	.22	11.5	.22	13.0	.30	12
	x	6.6	7.3	.14	8.0	.14	8.7	.14	9.3	.12	9.9	.12	7
	xx	6.0	6.8	.16	7.5	.14	8.1	.12	8.6	.10	9.0	.08	9
	xxx	6.8	7.5	.14	8.2	.14	8.7	.10	9.2	.10	9.4	.04	17
101 to 140...	o	15.0	15.7	.14	16.5	.16	17.5	.20	18.6	.22	19.8	.24	6
	x	14.5	15.1	.12	15.9	.16	16.7	.16	17.5	.16	18.3	.16	4
	xx	14.8	15.2	.08	15.7	.10	16.1	.08	16.5	.08	16.9	.08	6
	xxx	15.2	15.6	.08	15.9	.06	16.3	.08	16.7	.08	17.0	.06	4
201 to 240...	o	17.8	18.5	.14	19.3	.16	20.1	.16	21.1	.20	22.1	.20	5
	xxx	16.7	17.0	.06	17.4	.08	17.7	.06	17.9	.04	18.2	.06	5

TABLE 9.—*Comparison of the average height growth or accretion of 102 felled western yellow pine trees, for a 25-year period, grouped by age classes and degree of mistletoe infection.*

Age class.	Degree of infection.	Total height.		Accretion 1890–1895, periodic annual	Total height, 1900.	Accretion 1895–1900, periodic annual	Total height, 1905.	Accretion 1900–1905, periodic annual	Total height, 1910.	Accretion 1905–1910, periodic annual	Total height, 1915.	Accretion 1910–1915, periodic annual	Basis.
		1890	1895										
Years.		*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Trees.*
21 to 60	0	3.2	5.4	0.44	8.0	0.52	11.3	0.66	14.9	0.72	18.6	0.74	11
	x	2.6	5.1	.50	8.3	.64	12.2	.78	15.3	.62	18.2	.58	6
	xx	1.6	3.2	.32	4.6	.28	6.1	.30	7.4	.26	8.6	.24	7
	xxx	1.3	2.5	.24	3.8	.26	4.9	.22	5.7	.16	6.3	.12	5
61 to 100	0	27.4	31.5	.82	35.6	.82	39.5	.78	43.2	.74	46.6	.68	12
	x	29.6	32.2	.52	34.6	.48	36.8	.44	38.8	.40	40.8	.40	7
	xx	23.7	26.1	.48	28.3	.44	30.5	.44	32.1	.32	33.3	.24	9
	xxx	23.4	28.4	.40	30.0	.32	31.2	.24	32.2	.20	33.0	.16	17
101 to 140	0	58.9	61.5	.52	64.2	.54	66.9	.54	69.7	.56	72.5	.56	6
	x	49.4	51.8	.48	53.5	.34	55.0	.30	56.4	.28	57.5	.22	4
	xx	55.8	57.9	.42	60.0	.42	61.9	.38	63.5	.32	65.0	.30	4
	xxx	46.4	47.8	.28	49.0	.24	50.0	.20	50.6	.12	51.2	.12	4
201 to 240	0	75.5	76.7	.24	77.8	.22	78.9	.22	80.0	.22	81.2	.24	5
	xxx	71.4	72.0	.12	72.5	.10	73.0	.10	73.5	.10	74.0	.10	5

TABLE 10.—*Comparison of the average volume growth or increment of 102 felled western yellow pine trees, for a 25-year period, grouped by age classes and degree of mistletoe infection.*

Age class.	Degree of infection.	Total volume.		Increment, 1890–1895.		Total volume.	Increment, 1895–1900.		Total volume.
		1890.	1895.	Periodic annual.		1900.	Periodic annual.		1905.
Years.		*Cubic feet.*	*Cubic feet.*	*Cubic feet.*	*Per cent.*	*Cubic feet.*	*Cubic feet.*	*Per cent.*	*Cubic feet.*
21 to 60	0	0.36	0.54	0.036	(1)	0.80	0.052	(1)	1.19
	x	.02	.05	.006	.....	.20	.030	.....	.41
	xx	.01	.02	.002	.....	.08	.012	.....	.14
	xxx	.....	.....	.....	.....	.04	.008	.....	.08
61 to 100	0	3.77	5.40	.326	8.6	7.54	.428	7.9	10.23
	x	4.90	5.91	.202	4.1	7.10	.238	4.0	8.49
	xx	2.53	3.24	.142	5.6	3.98	.148	4.6	4.81
	xxx	4.12	4.94	.164	4.0	5.72	.156	3.2	6.46
101 to 140	0	35.10	39.78	.936	2.7	44.80	1.004	2.5	50.26
	x	25.95	30.15	.840	3.2	34.80	.930	3.1	39.20
	xx	23.72	26.35	.526	2.2	28.62	.454	1.7	30.75
	xxx	20.02	21.04	.204	1.0	22.87	.366	1.7	24.10
202 to 240	0	59.06	63.94	.976	1.7	69.38	1.088	1.7	75.72
	xxx	52.16	54.36	.440	.8	56.56	.440	.8	58.94

Age class.	Degree of infection.	Increment, 1900–1905.		Total volume.	Increment, 1905–1910.		Total volume.	Increment, 1910–1915.		Basis.
		Periodic annual.		1910.	Periodic annual.		1915.	Periodic annual.		
Years.		*Cubic feet.*	*Per cent.*	*Cubic feet.*	*Cubic feet.*	*Per cent.*	*Cubic feet.*	*Cubic feet.*	*Per cent.*	*Trees.*
21 to 60	0	0.078	(1)	1.81	0.124	(1)	2.67	0.172	(1)	11
	x	.042	.....	.86	.090	.....	1.25	.078	.....	6
	xx	.012	.....	.24	.020	.....	.37	.026	.....	7
	xxx	.008	.....	.18	.020	.....	.29	.022	.....	5
61 to 100	0	.538	7.1	13.52	.658	6.4	17.28	.752	5.6	12
	x	.278	3.9	9.89	.280	3.3	11.49	.320	3.2	7
	xx	.166	4.2	5.65	.168	3.5	6.52	.174	3.1	9
	xxx	.148	2.6	7.12	.132	2.0	7.70	.116	1.6	17
101 to 140	0	1.092	2.4	56.48	1.244	2.5	63.41	1.386	2.5	6
	x	.880	2.5	43.72	.904	2.3	48.07	.870	2.0	4
	xx	.426	1.5	32.70	.390	1.3	34.60	.380	1.2	4
	xxx	.246	1.1	25.32	.244	1.0	26.42	.220	.9	4
201 to 240	0	1.268	1.8	82.46	1.348	1.8	90.12	1.532	1.9	5
	xxx	.476	.8	61.38	.488	.8	64.00	.524	.9	5

[1] The periodic annual increment per cent was not computed for the 21 to 60-year age class because of the extremely small initial volumes and the proportionately great effect on the percentage of slight individual variations.

In the early stages of the study the trees were segregated by crown classes. Since by far the greater part of the trees in the open park-like stands studied were in the isolated, dominant, and codominant classes, the effects of crown class were found to be negligible in contrast to the marked effect of mistletoe in retarding the rate of growth. The retardation of growth due to the mistletoe was consistently evident in each age-crown class in which sufficient trees were secured to form a comparable basis. It was impossible to secure an equal number or equal proportion of each crown class in each age-infection class. As has been shown, it was found more necessary to segregate the felled trees by age-infection classes than by crown-infection classes. It was impracticable to segregate by crown classes all of the trees used in this study because of the extremely small number and in some cases entire lack of trees falling into each age-infection-crown class, had such a triple classification been used. The diameter, height, and volume growth during the 5-year period, 1910–1915, in the 21 to 60 year age class of the isolated trees included in Table 7, may be cited to show the injurious effect of mistletoe on growth within a given age-crown class, as follows:

Degree of infection.	Breast high diameter growth for last 5 years.	Height growth for last 5 years.	Volume growth for last 5 years.	Basis.
	Inches.	*Feet.*	*Cubic feet.*	*Trees.*
0	1.3	3.3	2.04	3
x	.8	2.0	.54	2
xx	.6	1.2	.25	3
xxx	(1)	.5	.004	4

[1] The trees in this class were less than 4.5 feet in height.

In Table 11 is shown increment data for two intensive sample plots aggregating 24 acres, located within the extensive plot on the Tusayan National Forest mentioned below, the data being grouped according to degree of infection. An accelerated growth is noted in the x infection class comparable to that noted in Table 1, the explanation of which is not evident from the data at hand, unless it be an actual stimulation due to the presence of the mistletoe. The decrease in the rate of growth in the heavily infected class is very marked and is in accord with all of the other results secured in this study.

Two seedlings, one healthy and the other heavily infected with mistletoe, which were growing side by side on a good site, were analyzed and both found to be 15 years old. The healthy seedling showed marked vigor and was 4 feet tall, whereas the one infected with mistletoe was only 3 feet tall and showed evident stunting and that death was imminent.

Three successive stages in the early development of mistletoe on twigs of western yellow pine and the formation of swellings by mistletoe.

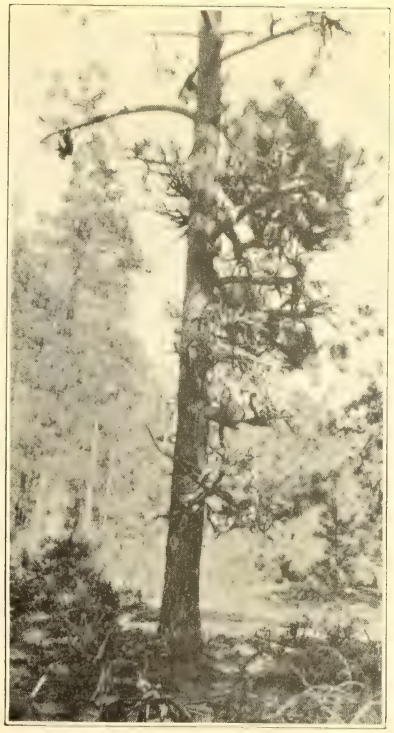

FIG. 1.—A western yellow pine tree showing stunted branches and witches' brooms in the lower part of the crown caused by mistletoe. Santa Fe National Forest, New Mexico.

FIG. 2.—Two "black jacks" in the foreground and a "yellow pine" in the background killed by mistletoe. The "black jacks" were killed recently while the "yellow pine" has been dead for a number of years. Coconino National Forest, Arizona.

FIG. 3.—A western yellow pine tree recently killed by mistletoe. Coconino National Forest, Arizona.

PLATE III.

The data presented in the preceding pages show that, although minor fluctuations are exhibited, the rate of growth of the host decreases with the amount of mistletoe infection; or, in other words, is dependent on the degree of parasitism. Possible exceptions may be cases of very light infection which appear to act as stimulants for the host tree. These results are really to be expected when the effects of mistletoe parasitism are fully understood.

TABLE 11.—*The effect of mistletoe infection on the rate of growth of western yellow pine on two intensive sample plots aggregating 24 acres on the Tusayan National Forest.*

Degree of infection.	Average diameter growth, 1914–1919.	Periodic annual increment, 1914–1919.	Periodic annual increment, 1914–1919.[1]	Total volume of class, 1919.	Basis (number of trees, 4 inches and over d. b. h.).
	Inches.	*Cubic feet.*	*Per cent.*	*Cubic feet.*	
0	0.70	4.56	2.54	1,636.2	359
x	.88	5.65	2.79	553.9	98
xxx	.49	2.23	1.83	254.5	114

[1] On cubic-foot basis.

NOTE.—Since there were only 13 trees classed as moderately infected, they were omitted because of the small basis.

EFFECT ON LIMBS.

The first visible effect of the infection of a limb by mistletoe is the formation of a fusiform swelling (Pl. II) about the center of infection similar to those occasionally found on stems. This hypertrophy is the first stage of a later abnormal growth of branches from the enlarged portion, which results in the formation of witches' brooms. (Pl. III, Fig. 1.) When the stimulus of the parasite has once become manifest through the formation of a broom, the tendency toward abnormal branching continues, although the aerial parts of the mistletoe have may died.

The comparative diameter growth or accretion of 54 limbs on 18 standing black jacks is averaged by infection classes in Table 12. Measurements were taken at 6 inches from the bole of the tree and at 6-inch intervals beyond this point. The measurements taken at 6 to 18 inches from the bole of the tree were averaged and are presented in the table to facilitate a clearer and more comprehensive interpretation of the significant data. Limb measurements were also taken on the felled trees to check the comparative growth of the healthy and mistletoe-infected limbs of the standing trees. From these data, which are summarized in Table 13, it is apparent that the limbs had been infected at least 25 years prior to the time at which they were analyzed. The data presented in both tables show that, for the limbs examined, the rate of growth in diameter of limbs infected with mistletoe is greater than that of uninfected limbs. It is

very probable that the increased diameter growth continues to a certain point, beyond which there is a pronounced decrease in the rate of growth, until the limb eventually dies. This increased diameter growth is probably caused by the formation of an excessive amount of pathological parenchyma tissue, as a result of the irritation of the cambium by the parasite. The softer parenchyma adjacent to the center of infection renders the infected wood somewhat weaker than the more highly-lignified tissues of normal, uninfected wood. The presence of the mistletoe in the limb produces a stimulated growth of the host near the center of infection.

TABLE 12.—*Comparison of the average diameter growth or accretion of 54 limbs on 18 standing black jacks, for a 5-year period, grouped according to degree of mistletoe infection.*

Degree of infection.	Average diameter.[1]		Accretion, 1910–1915.		Basis.
	1910	1915	Periodic.	Periodic annual.	
	Inches.	*Inches.*	*Inch.*	*Inch.*	*Limbs.*
0	3.84	3.98	0.14	0.028	20
x	3.90	4.06	.16	.032	6
xx	4.35	4.62	.27	.054	7
xxx	4.08	4.46	.38	.076	21

[1] Average of two sets of measurements taken at 6 and 18 inches from the bole of the tree.

TABLE 13.—*Comparison of the average diameter growth or accretion of 8 limbs on 4 felled western yellow pine trees, for a 25-year period, grouped according to degree of mistletoe infection.*

Degree of infection.	Average diameter.[1]		Accretion, 1890–1895.	Average diameter.[1]	Accretion, 1895–1900.	Average diameter.[1]	Accretion, 1900–1905.	Average diameter.[1]	Accretion, 1905–1910.	Average diameter.[1]	Accretion, 1910–1915.	Basis
	1890	1895	Periodic annual.	1900	Periodic annual.	1905	Periodic annual.	1910	Periodic annual.	1915	Periodic annual.	
	In.	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*Limbs*
0	1.68	1.84	0.032	2.01	0.034	2.21	0.040	2.34	0.026	2.46	0.024	4
xxx	3.06	3.32	.052	3.68	.072	4.04	.072	4.34	.060	4.56	.044	4

[1] Average of two sets of measurements taken at 6 and 18 inches from the bole of the tree.

Eccentricities, especially hyponastic growth, are considerably more pronounced in limbs heavily infected with mistletoe than in healthy limbs. The formation of a large witches' broom produces an abnormally heavy load which must be borne by that portion of the limb nearest to the bole of the tree. This abnormal load produces stresses sufficient to stimulate the formation of wood on the under side of the limbs through the deposition of food materials, which enables the wood to withstand the compression below. The tension above is over-

come by the development of a special tissue on the upper side of the limb.

The increased size of the limbs infected with mistletoe renders limbing and brush disposal in logging operations more difficult and consequently more expensive. The excessive secretion of resin which occurs in mistletoe-infected limbs has somewhat the same effect on brush disposal.

HYPERTROPHY AND RESIN FLOW.

Although mistletoe infection causes swellings on both branches and trunks, the stem swellings frequently become less noticeable as the tree grows. In many cases there are no pronounced swellings on the larger boles even when very old mistletoe infections are present, about the only means of detecting the infection being the presence of the mistletoe or the unusual roughness of the bark. (Pl. IV, Fig. 1.) When, however, infection occurs during the early life of the tree, it frequently results in the formation of a burl which may attain very conspicuous proportions. The fusiform swellings on both the stems and limbs resulting from mistletoe infections are centers where abnormal amounts of food materials are stored, which condition is evidently stimulated by the decided pathogenic tendencies of the mistletoe. The cortex is frequently gnawed from the lesions by rodents, especially porcupines and squirrels, attracted by the soft spongy nature and the greater thickness of the inner bark of mistletoe-infected branches and stems. This fact establishes a casual relationship between mistletoe infection and rodent injury.

As previously stated, there is more or less hypertrophy at the point of mistletoe infection on both limbs and stems. This hypertrophy is frequently accompanied by a copious flow of resin, which appears as small drops, usually on the lower side of limbs, which are heavily infected with mistletoe. A cross section through such a limb shows large areas of the sapwood thoroughly infiltrated with resin. The process of infiltration continues on many of the limbs until the fibrovascular system is thoroughly clogged with resin: the limb is girdled as far as receiving any food supply is concerned, and is finally killed. This process is usually very gradual, but none the less sure.

The resin flow from such mistletoe-infected limbs is not caused by insect punctures. A careful examination of the resin-infiltrated areas fails to show any signs of such injury. On many of the trees which are heavily infected with mistletoe, resin cankers (Pl. IV, Fig. 2) of varying sizes are found on the bole. These cankers are often directly associated with local mistletoe infection. The resin flows on the bole are usually indicative of the decline of the tree; in fact, trees with marked resin-flow cankers usually die in a relatively short time.

EFFECT ON THE FOLIAGE.

Tables 14, 15, and 16 show the effects of the mistletoe on the foliage of the western yellow pine. The data included in Table 16 were obtained as follows:

Each tree crown was divided into three divisions—bottom, middle, and top—including in each division about one-third of the total leaf surface. One hundred tufts from each section were selected at random and measured; the mean length of these tufts was taken as the average length per tuft for that section. Then 10 tufts of this average length were taken from each of the three sections into which the crown had been divided. These tufts, 30 in all for each tree, were cut off and taken to the laboratory, where the number of leaves per tuft, the length, and the width of each leaf were determined. The total number of tufts in the bottom, middle, and top thirds was determined by actual count. The number of tufts thus obtained was multiplied by the average number of leaves found in the 10 tufts from each section. This gave the average number of leaves in each section. The sum of the leaves in the three sections gave the average number of leaves in any given tree crown.

TABLE 14.—*Comparison of the length of leaves of 103 western yellow pine trees, classified according to degree of mistletoe infection.*

Degree of infection.	In lower portion of crown.			In central portion of crown.			In upper portion of crown.			Mean for entire crown.			Basis.
	Mean minimum.	Mean Maximum.	Average.	Mean minimum.	Mean maximum.	Average.	Mean minimum.	Mean maximum.	Average.	Mean minimum.	Mean maximum.	Average.	
	In.	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*Trees.*
0	3.3	6.2	4.9	3.8	6.3	5.5	4.2	6.9	5.8	3.8	6.5	5.4	38
x	2.3	5.3	4.0	2.5	5.9	4.5	3.3	6.2	5.0	2.7	5.8	4.5	15
xx	2.1	5.3	3.8	2.5	5.4	4.1	2.9	5.7	4.6	2.5	5.5	4.2	18
xxx	2.1	5.1	3.6	2.4	5.1	4.0	2.7	5.1	4.0	2.4	5.1	3.9	32

TABLE 15.—*Comparison of the length of leaf tufts of 97 western yellow pine trees, classified according to degree of mistletoe infection.*

Degree of infection.	In lower portion of crown.			In central portion of crown.			In upper portion of crown.			Mean for entire crown.			Basis.
	Mean minimum.	Mean Maximum.	Average.	Mean minimum.	Mean maximum.	Average.	Mean minimum.	Mean maximum.	Average.	Mean minimum.	Mean maximum.	Average.	
	In.	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*Trees.*
0	3.4	11.5	6.7	5.4	15.5	10.0	6.8	22.7	13.8	5.2	16.6	10.2	37
x	3.0	10.1	6.5	4.0	12.0	8.0	5.5	16.8	10.3	4.2	13.0	8.3	15
xx	2.4	8.2	4.9	2.3	9.1	5.2	3.4	11.1	7.3	2.7	9.4	5.8	15
xxx	2.3	8.1	4.5	2.6	8.6	5.0	2.4	8.5	4.8	2.4	8.4	4.8	30

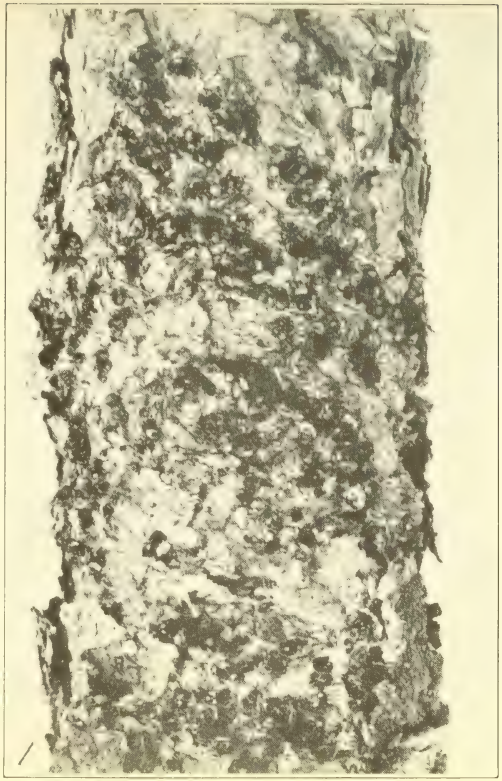

FIG. 1.—Concentric rings of advance of a mistletoe lesion on western yellow pine.

FIG. 2.—A resin canker developing in an old mistletoe lesion on western yellow pine.

FIG. 1.—A small branch of western yellow pine showing fewer and smaller leaves and shorter internodes due to the mistletoe, of which three local infections may be seen. One-sixth natural size.

FIG. 2.—A small branch of western yellow pine showing the larger leaves and longer internodes developed on a healthy tree in the same group from which the branch shown in Figure 1 was secured. One-eighth natural size.

TABLE 16.—*The effects of mistletoe on the photosynthetic surface of western yellow pine.*

Tree number.	Degree of infection.	Age.	Diameter breast high outside bark.	Total height.	Total volume.	Crown.		Crown class.
						Width.	Length.	
		Years.	*Inches.*	*Feet.*	*Cubic feet.*	*Feet.*	*Feet.*	
103	xxx	80	7.5	20.0	2.50	10.0	15.5	X
104	o	79	14.5	42.0	19.00	17.0	32.0	X
105	xxx	83	8.1	26.0	3.55	8.5	18.5	C
106	o	83	15.2	49.0	22.50	22.0	42.0	C
107	o	37	7.1	21.0	2.40	12.0	18.0	D

Length of leaf tufts.

Tree number.	Lower portion of crown.				Center of crown.				Upper portion of crown.				Mean for entire crown.		
	Minimum.	Maximum.	Average.	Number of tufts.	Minimum.	Maximum.	Average.	Number of tufts.	Minimum.	Maximum.	Average.	Number of tufts.	Minimum.	Maximum.	Average.
	In.	*In.*	*In.*		*In.*	*In.*	*In.*		*In.*	*In.*	*In.*		*In.*	*In.*	*In.*
103	0.5	7.0	3.2	81	1.0	8.0	3.8	329	1.0	12.0	5.7	234	0.8	9.0	4.2
104	1.0	11.3	5.3	2,161	2.0	13.0	5.4	2,390	2.0	18.0	8.0	1,151	1.6	14.1	6.2
105	.3	11.0	3.7	242	.5	12.0	4.0	183	.6	13.0	5.0	176	.4	12.0	4.2
106	1.0	11.0	4.0	1,522	1.5	17.0	6.7	1,228	2.0	26.0	7.7	445	1.5	18.0	6.1
107	1.5	12.5	6.8	379	2.5	18.0	8.8	321	2.5	28.0	10.0	313	2.1	19.5	8.5

Tree No.	Total number of tufts in entire crown.	Length of leaves.							
		Lower portion of crown.				Center of crown.			
		Mean minimum.	Mean maximum.	Mean average.	Number of leaves.	Mean minimum.	Mean maximum.	Mean average.	Number of leaves.
		In.	*In.*	*In.*		*In.*	*In.*	*In.*	
103	644	1.6	3.3	2.6	13,122	1.7	3.5	2.6	62,181
104	5,702	2.5	4.9	3.5	518,640	2.8	5.1	3.7	803,040
105	601	2.0	4.1	3.2	109,142	2.3	4.2	3.1	67,161
106	3,195	4.1	5.8	4.9	365,280	4.4	6.7	5.7	289,808
107	1,013	3.3	5.2	4.5	94,371	4.1	5.7	5.1	172,972

Tree No.	Length of leaves.						
	Upper portion of crown.				Mean for entire crown.		
	Mean minimum.	Mean maximum.	Mean average.	Number of leaves.	Mean minimum.	Mean maximum.	Mean average.
	In.	*In.*	*In.*		*In.*	*In.*	*In.*
103	1.8	4.5	3.2	84,240	1.7	3.7	2.8
104	2.8	5.1	4.1	470,759	2.7	5.0	3.7
105	3.1	5.0	4.3	85,712	2.4	4.4	3.5
106	4.8	6.8	5.9	182,005	4.4	6.4	5.5
107	5.2	6.4	5.9	152,431	4.3	5.7	5.1

TABLE 16.—*The effects of mistletoe on the photosynthetic surface of western yellow pine*—Continued.

Tree No.	Total number of leaves in entire crown.	Leaf surface.				Ratio of leaf surfaces.	Ratio of volumes.[1]
		Lower portion of crown.	Central portion of crown.	Upper portion of crown.	Entire crown.		
		Square inches.	*Square inches.*	*Square inches.*	*Square inches.*		
103	159,543	4,094.1	19,400.4	32,348.2	55,842.7	1.0	1.0
104	1,792,439	217,828.8	356,549.8	231,613.4	805,992.0	14.4	7.6
105	262,015	40,910.5	24,983.9	44,427.4	110,321.8	2.0	1.4
106	837,093	218,438.4	198,228.7	128,939.5	545,606.6	9.8	9.0
107	419,774	50,960.3	105,868.9	107,921.4	264,750.6	4.7	.96

[1] In these ratios Tree No. 103 is taken as unity.

The average length and width of the leaves in the 10 tufts selected were used in determining the leaf surface for a given section of the crown, and this in turn for finding the total leaf surface of a given tree. Table 16 shows that not only does the mistletoe shorten the length of both leaf tufts and leaves, but it also materially decreases the number of leaf tufts per tree for heavily infected trees when compared with healthy trees of the same age and site conditions. (Pl. V.) When two trees of the same size, one healthy and the other heavily mistletoed, are compared—Trees No. 103 and No. 107, for instance—it is seen that it has taken the mistletoe-infected tree more than twice the number of years to reach the same size as the healthy tree. The average ratio of the leaf surface in square feet to the total volume in cubic feet for the healthy trees given in Table 16 is 409.7 compared with 185.5 for the heavily infected trees.

Trees heavily infected with mistletoe not only have considerably shorter leaves and leaf tufts than healthy trees, but the leaves of mistletoe-infected trees are lighter in color than those of healthy trees, being a yellowish green as compared with the olive green on the healthy trees. Each heavy infection causes a localization and reduction of the photosynthetic or assimilatory leaf surface of the tree, which in turn results in a marked decrease in the rate of growth.

EFFECT ON LONGEVITY OF HOST.

A number of permanent sample plots were established on the Coconino and Tusayan National Forests by the Fort Valley Forest Experiment Station, in 1909, to determine the rate of growth and decadence, the rate of establishment of natural reproduction, and the effect of various factors upon regeneration on cut-over areas. These plots were remeasured in 1914 and 1919. Some of the plots yielded valuable data on the amount of mistletoe infection and the resulting mortality on cut-over areas.

On an area of 456 acres on the Tusayan National Forest about 5 miles from the Fort Valley Forest Experiment Station, 2,636 black jacks, or 34.9 per cent of the total number on the plot, and 225 yellow pines, or 34.8 per cent of the total number, were infected with mistletoe in 1914. In 1919, 2,335 black jacks, or 28.8 per cent of the total number of trees 4 inches in diameter and over, were infected with mistletoe. In many instances the infection was not sufficient to render the tree unhealthy, but with the increase of infection many of the infected trees will pass through the various infection classes and eventually die.

All of the trees which had died on the plots during the two 5-year periods were carefully examined and the cause of death noted. On the plot of 456 acres on the Tusayan National Forest 170 black jacks died from various causes during the first 5-year period, or 2.2 per cent of the total number of black jacks living on the plot in 1909, while 21 yellow pines died during the 5 years, which is 3.4 per cent of the total number of yellow pines living on the area. During the 5-year period from 1914 to 1919, 127 black jacks died from mistletoe alone, or in conjunction with other agents such as insects, porcupines, etc.

On a plot of 135 acres located on the Coconino National Forest about 1½ miles from the Fort Valley Forest Experiment Station, 27 black jacks died from various causes during the first 5 years, which is 1.1 per cent of the total number of black jacks living on the plot in 1909; 26 yellow pines, or 1.8 per cent of the total number, died during the same period.

A digest of that part of the detailed records pertaining to mistletoe as a cause of the death of western yellow pine during the 5-year period from 1909 to 1914 is given in Table 17. The 456-acre plot on the Tusayan National Forest is located on an area which has sustained heavy losses from mistletoe, while the 135-acre plot on the Coconino is located on an area with only occasional heavy infections. A study of Table 17 indicates the mortality of western yellow pine on these two areas and the extent to which mistletoe was a direct cause or a contributing factor. A study of Table 17 also indicates that of the 170 black jacks on the Tusayan plot which died during the 5-year period 26.4 per cent were killed directly by mistletoe, 42.3 per cent by mistletoe combined with other agents, and only 31.3 per cent died from other causes; while only 4.8 per cent of the yellow pines were killed by mistletoe combined with bark beetles. On the 135-acre Coconino plot mistletoe infection alone resulted in the death (Plate III, Fig. 2) of 7.5 per cent of the total number of dead black-jacks and 7.9 per cent of the total number of dead yellow pines, while mistletoe was a contributing factor toward the death of an additional 20.2 per cent of the yellow pines. During the 5 years 1.5 per cent

of the total number of black jacks on the Tusayan plot in 1909 were killed by mistletoe alone or in conjunction with other agents, mainly insects. While this figure itself is not high, it is alarming because the indications are that the death rate will increase from year to year, and although an effort was made to have all heavily infected trees removed when this area was marked for cutting, it is evident that mistletoe did not receive the attention which it deserved.

TABLE 17.—*Classification of dead trees on permanent sample plots of 456 acres on the Tusayan and 135 acres on the Coconino National Forest.*

Cause of death.	Per cent of dead trees, 1909–1914 (based on total number of trees which died during 5-year period).			
	456-acre plot, Tusayan National Forest.		135-acre plot, Coconino National Forest.	
	Black jack.	Yellow pine.	Black jack.	Yellow pine.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Mistletoe	26.4	.....	7.5	7.9
Mistletoe and insects	35.0	4.8	.....	20.2
Mistletoe and porcupine	5.5	.....	.....	.....
Mistletoe and suppression	1.4	.....	.....	.....
Mistletoe, porcupine, and insects	.4	.....	.....	.....
All other causes	31.3	95.2	92.5	71.9
Total	100.0	100.0	100.0	100.0

Weir [4] has noted the same direct relation between mistletoe infection and insect infestation in the Northwest, especially with *Dendroctonus valens*. The origin of numerous insect infestations has been traced to stands of western yellow pine heavily infected with mistletoe.

The main difference between mistletoe and insect injury is in the length of time required for the injury to become manifest. A sporadic insect infestation may develop rapidly and may kill a large number of trees in a relatively short time, and it may even continue to increase until it is overcome and reduced to normal proportions through some natural agency. Mistletoe, on the other hand, develops slowly but continuously and persistently. The bark beetles, when attracted by the resinuous exudations of the mistletoe-infected trees, may materially hasten the death of the host which has already been weakened by the parasitic mistletoe. Trees dead or dying from mistletoe infection have been found infected with species of secondary bark beetles and borers, such as Ips, Pityophthorus, Chrysobothris, and Melanophila.

Three black-jack saplings under 4 inches in diameter breast high on one of the intensive mistletoe-study plots died during the five-year

[4] Weir, James R., Mistletoe Injury to Conifers in the Northwest. U. S. Dept. Agri. Bulletin 360, 39 pp., 1916.

period as a direct result of mistletoe infection. Five yellow pines on the same area were also killed by mistletoe during the same period. Many of the other trees on the sample plots, although not dead at the last examination, were small and stunted; they were making an almost inappreciable growth and were very unhealthy in appearance. Some of these, which are apparently unable to endure the parasitism of the mistletoe combined with a rather adverse climate, will undoubtedly succumb before the remeasurement of the plots at the end of the next five-year period. Practically all of the trees which are heavily infected with mistletoe are ultimately doomed, since it is only a question of the length of time during which they can withstand the insidious action of the parasite.

EFFECT OF MISTLETOE ON MERCHANTABILITY OF TIMBER.

Although the mistletoe injury to the host results less in the depreciation of the lumber than in the impairment of the vital physiological functions of the tree, there is nevertheless an appreciable effect on the quality of the lumber. The accelerated growth of mistletoe-infected limbs, as shown in Tables 12 and 13, results in larger limbs which produce knots of a larger size in the lumber that is sawed from the boles of the mistletoe-infected trees. The number of knots is also increased by the greater number of secondary branches and twigs in stem infections. The increased size and number of the knots may, in many cases, be sufficient to lower materially the grade of the lumber.

Mistletoe-infection produces a curly or abnormally grained wood and weaker lumber. Wood invaded by the thread-like sinkers of the mistletoe is spongy, and is frequently discolored and pitchy, as a result of the resinous flow or bleeding of the trees. The presence of mistletoe burls renders a tree more susceptible to wind breakage; in addition, it may ruin a portion or all of a sawlog. A seedling or sapling whose stem is infected with mistletoe will seldom develop a bole large enough to yield any considerable quantity of lumber and very rarely, if at all, lumber of a high grade. It is therefore evident that, aside from the physiologically injurious effect of the mistletoe, it also introduces a cull factor in that mistletoe-infected trees produce a poorer grade of lumber than healthy trees.

EFFECT OF MISTLETOE ON SEED PRODUCTION OF HOST.

Pearson [5] has shown that, as a result of a collection in 1909, seed from mistletoe-infected black jacks gave a germination of 17 per cent below that of healthy black jack, which had a final germination of 78 per cent. The present study leads to the conclusion that,

[5] Pearson, G. A. The Influence of Age and Condition of the Tree Upon Seed Production in Western Yellow Pine. U. S. Dept. of Agri., Forest Service Cir. 196, 1912.

although the mistletoe may stimulate growth in that portion of the host adjacent to the parasite, causing the abnormal development of certain limbs and branches into witches' brooms, the excess of carbohydrates produced by the additional foliage of the mistletoe-stimulated branches is consumed by the parasite, thereby reducing the amount available for the seeds. The effect upon the host in all cases is insidious, slowly depriving the tree of its vitality instead of causing injuries in the nature of a shock, as in the case of burns and other mechanical injuries. In this and the following study, no information was available as to the influence upon seed production of the condition of other trees which may have supplied the pollen for fertilizing the seed tree. Because of the lack of pollination experiments, the conclusions are necessarily based wholly upon the condition of the tree from which the seed was collected.

In order to check this theory further, additional seed collections were made by the Fort Valley Forest Experiment Station in 1913 and 1915 from mistletoe-infected and healthy western yellow pines. Aside from the difference in degree of mistletoe infection, the trees were otherwise normal and very similar in age and crown development. The seed extractions and germination tests were conducted separately for each tree. Five hundred seeds from each lot were germinated in sand in the greenhouse at a temperature ranging from 40° to 90° F., with a mean daily temperature of approximately 65° F. Daily counts were made during the progress of the germination tests, which continued for approximately 50 days.

The pertinent data on the seed production of 64 felled western yellow pine trees for the 1913 and 1915 collections are classified in Table 18, according to the degree of mistletoe infection. The best criterion by which to judge the relative seed production is believed to be the reproductive value of each tree or the total number of viable seeds produced per tree, which represents a convenient summation of the fundamental variables of seed production. This is obtained by multiplying the yield per tree in pounds of clean seed by the number of clean seeds per pound, and in turn multiplying the product by the final germination per cent. It will be noted that, with the exception of the lightly infected class upon which the mistletoe appears to have a slight stimulating effect, there is a decrease in the percentage of germination, the yield of cones, and clean seed per tree and consequently a marked decrease in the reproductive value per tree with an increase in the amount of mistletoe infection. The reproductive value of the trees in the intermediate infection class is about 40 per cent of that of the healthy class, while the reproductive value of the trees in the heavily infected class falls to only about 25 per cent of that of the healthy class. This is not surprising when the effects of the parasitism are fully understood. The data for the mistletoe-infected classes of

felled trees reported in Table 18 are meager because of the difficulty experienced in securing seed from mistletoe-infected trees, owing to the sterility of the cones and their failure to develop. In fact, a diligent search was made for heavily mistletoed trees which were bearing seed, but very few were found.

TABLE 18.—*Data on the seed production of 64 felled western yellow pine trees classified according to degree of mistletoe infection.*

Degree of infection.	Final germination.	Clean seeds per pound.	Yield per tree.		Reproductive value per tree.	Basis.
			Cones.	Clean seed.		
1913 collection:	*Per cent.*	*Number.*	*Bushels.*	*Pounds.*	*Number of viable seeds.*	*Number of trees.*
0	82.8	14,473	0.8	1.08	12,942	43
x	84.1	14,385	1.0	1.10	13,292	2
xx	81.7	13,314	.5	.45	4,895	2
xxx	77.0	14,475	.3	.31	3,455	2
Mean of x, xx, and xxx	80.9	14,058	.6	.62	7,052	6
1915 collection:						
0	53.2	12,156	1.1	.83	5,626	11
Mean of x, xx, and xxx	47.1	14,170	.9	.37	2,202	4

The extent and condition of the seed crop on the standing trees on the permanent sample plots were under observation from 1912 to 1916 in order to secure additional data on the effect of mistletoe infection on the amount and periodicity of seed production. The 1912 seed crop was rather light; only a few of the trees bore any large quantity of cones. In 1913 there was an average crop, with practically none in 1914, while the 1915 seed crop was somewhat below the average.

The records of the 1912 and 1915 seed crops for 90 of the living western yellow pines are classified in Table 19 by degree of mistletoe infection and amount of the seed crop. The seed crops were arbitrarily classified by the observer as heavy, good, medium, light, or none. An analysis of the data shows that the amount of seed production varies inversely with the degree of mistletoe infection. As the degree of mistletoe infection increases the amount of seed produced decreases until very little, if any, seed is produced by heavily infected trees.

These results are further substantiated by observations of the writers covering a period of approximately 10 years. Trees heavily infected with mistletoe produce small amounts of seed at such times as there are generally heavy seed crops, and at other times practically none. The few cones that may occasionally be found on trees heavily infected with mistletoe are very often aborted, and are frequently infested with a cone insect (*Conophthorus ponderosæ*).[6]

[6] Material determined by Office of Forest Insect Investigations, Bureau of Entomology, U. S. Dept. of Agriculture.

TABLE 19.—*Record of 1912 and 1915 seed crops for 90 standing western yellow pine trees classified by degree of mistletoe infection and amount of seed crop.*

Degree of infection.	Amount of seed crop.										Total basis.
	Heavy.		Good.		Medium.		Light.		None.		
1912 seed crop:	*Number of trees.*	*Per cent.*	*Number of trees.*	*Per cent.*	*Number of trees.*	*Per cent.*	*Number of trees.*	*Per cent.*	*Number of trees.*	*Per cent.*	*Trees.*
0	0	0	0	0	2	5.3	9	23.7	27	71.0	38
x	1	7.7	0	0	1	7.7	4	30.8	7	53.8	13
xx	0	0	0	0	0	0	5	25.0	15	75.0	20
xxx	0	0	0	0	0	0	0	0	16	100.0	16
1915 seed crop:											
0	0	0	1	2.8	2	5.5	15	41.7	18	50.0	36
x	0	0	0	0	2	14.3	5	35.7	7	50.0	14
xx	0	0	0	0	0	0	4	18.2	18	81.8	22
xxx	0	0	0	0	0	0	0	0	18	100.0	18

A similar deterrent effect of mistletoe on the seed production of Douglas fir, western larch, and lodgepole pine has also been found by Weir [7] to obtain in the Northwest, where seed collected from very old mistletoe brooms showed a germination on an average of 10 per cent below that of seed taken from uninfected branches of the same trees. Munns [8] reports that Jeffrey pine trees infected with mistletoe had half as many more seed to the pound as were found in the cones on thrifty trees, but the germination was 20 per cent lower and the seedlings produced were not so vigorous. It seems very improbable that moderate or heavy mistletoe infection would ever act as a stimulus upon seed production, because its slow, insidious action makes constantly greater demands upon the vitality of its host. Trees moderately or heavily infected with mistletoe are therefore of little or no value for the purpose of seed production.

The fact is fundamental in silviculture that variations in the individual characteristics of the parent trees are hereditarily transmitted through the seed.[9] The extent to which the origin of the seed influences such characteristics as the resistance or immunity to disease, the rate of growth, and the growth-form of the regenerated forest, is of vital importance in the rational practice of scientific forestry.

The experiments of Zederbauer [10] indicate that trees grown from seed collected from intermediate, suppressed, and weakened trees are less resistant to disease than trees grown from seed produced by dominant and vigorous trees. The hereditary characters of the species are not changed materially during one rotation. Several generations are necessary to show the true effects of those characteristics

[7] Weir, James R. Mistletoe Injury to Conifers in the Northwest. U. S. Dept. of Agri. Bul. 360, 1916.

[8] Munns, E. N. Effect of Fertilization on the Seed of Jeffrey Pine. Plant World, 22: 138–144, 1919.

[9] Engler, Arnold. Einfluss der Provenienz des Samens auf die Eigenschaften der forstlichen Holzgewächse. Mitteilungen der Schweizerischen Centralanstalt für das forstliche Versuchswesen, Zürich, 1905, B. 8, s. 81–236; 1913, B. 10, s. 1–386.

[10] Zederbauer, E. Centralblatt für das gesammte Forstwesen, 1912, s. 201.

of the parent tree which may be transmitted through the seed, such as an unusual divergence from the typical silvical characteristics of the species. A clearer conception of the latent possibilities of disease resistance and immunity of a species obtained through tree breeding is of vast importance in the silvicultural improvement and management of the forest. The hereditary influence of the parents upon the offspring is a well-recognized factor in genetics. This factor is doubly important in forestry, not only in the collection of seed for artificial regeneration, but also in the selection of seed trees to provide for the natural reproduction of cut-over forests. In timber-sale practice only thrifty seed trees should be left and all diseased and suppressed trees should be removed in order to improve the condition of the forests of the future.

SILVICULTURAL ASPECT OF MISTLETOE INFECTION.

The destruction caused by disease promises to approach or even surpass the losses from fire on the national forests of the Southwest, now that the development of fire protection has reduced the fire hazard. Mistletoe injury presents one of the most serious phases of this silvicultural problem. The parasite may be slow in effecting its injury, but it is unquestionably sure.

A brief discussion of some of the salient objects of silviculture is essential to a complete understanding of the significance of any methods of control which may be attempted. The chief fundamentals of silviculture, as applied in the regeneration of western yellow pine stands, are to maintain the continuity of the forest and to increase its productivity. A number of basic considerations must be taken into account under any rational method of cutting, among which may be mentioned the silvics of the species, the fire hazard and liability, exploitation and economic conditions, and the removal of the decadent, unhealthy, and overmature timber as rapidly as possible, to avoid waste through decay. All defective, diseased, and suppressed trees should be marked for cutting unless needed as fire insurance or seed trees. No defective or diseased tree should be left standing if it is evident that it will not live until the next cutting, unless it is absolutely required for silvicultural purposes. When it becomes necessary to reserve trees among the large diameter classes, thrifty, healthy trees of good form should be selected, since the condition of the progeny is influenced by heredity as well as by soil and climate. Increased forest productivity will be realized if, in the application of the above principles, the forester will also strive to eliminate the deterioration of merchantable material. It is thus evident that the marking on each individual area must be varied to meet the silvicultural requirements of the forest. The importance of careful, intelligent marking on timber-sale areas can not be over-

estimated, since this is the practicable means by which rational silvicultural management is actually secured.

Meinecke [11] has suggested the establishment of pathological rotations for species of economic importance which are subject to serious diseases. A pathological rotation may be defined as the period during which the timber crop may grow and be subject to exploitation at a profit, but beyond which rapid deterioration is imminent and the product will be marketed at a great reduction in value. The pathological rotation is therefore a limiting factor; and, with regard to heartwood-destroying fungi entering the heartwood through open wounds, it is based upon the age of decline or the age at which even unwounded trees become subject to heavy infection because they are unable to throw off the parasite or to hold its growth in check. From the discussion in the earlier part of this bulletin it will be seen that the mistletoe may kill small seedlings only a few years old, as well as veteran western yellow pines 200 to 300 years old. It is therefore evident that it would not be practicable to attempt to establish a pathological rotation for mistletoe-infected western yellow pine.

CONTROL OF MISTLETOE.

Any method of control of this serious and widely distributed enemy of the western yellow pine forests of the Southwest must be adapted to existing conditions. As in the case of other diseases, prevention is the basis for control. The protection of healthy stands of timber from disease is accomplished mainly by removing the source of infection.

Mistletoe is more susceptible to control measures than many fungi. Infection is confined to the aerial parts of the host, while fungi may infect the subterranean as well. The seeds of the mistletoe, which are much larger than the microscopic spores of fungi, are not subject to such wide dissemination. Mistletoe is killed with the death of its host, whereas certain fungi may remain alive for an indefinite period following the death of their hosts.

It is evident also that mistletoe develops rapidly after cutting, since many of the trees left standing on the permanent sample plots were killed by mistletoe during the five years following the logging operation; and many more, although still alive, will die in the course of a comparatively few years. In this study mistletoe was found to be directly or indirectly responsible for the greater number of deaths of western yellow pine.

All of the facts at hand indicate that the cutting of mistletoe-infected trees is the only practicable method of control. Since mistletoe appears to spread more rapidly and to grow faster on lightly infected trees, as a result of increased wind and light following

11 Meinecke, E. P. Forest Pathology in Forest Regulation. U. S. Dept. of Agri. Bul. 275, p. 59, 1916.

cutting and providing more favorable conditions for the optimum development of the parasite, every effort should be made to free the stand entirely of mistletoe infection, although it is doubtful whether in certain cases the removal of lightly infected trees would be warranted because of silvicultural reasons. The increased activity of the mistletoe following the opening of the stand militates against leaving for a future cutting operation any but lightly infected trees, the infection of which is confined to the lower portion of the crown. Old and heavily infected trees should be cut for two reasons: (1) To improve the hygienic condition of the forests of the future through the removal of the mistletoe, and (2) to secure the maximum realization on a rapidly diminishing growing stock or forest capital. Since the future productivity of the forests depends to a great extent upon the proper choice of seed trees or of the seed itself in the case of artificial regeneration, those trees used for reproductive purposes should be sound, healthy, and of an intermediate age class.

As heavy a stand of healthy trees as possible should be left in order to compensate for the removal of diseased trees, and to maintain better forest conditions, reduce wind damage, and insure a denser stand of reproduction. Exceptional care should be taken to leave every healthy black jack which is free from infection. Wherever possible, trees should be freed from light infections by cutting off lower branches within reach. Transition trees and vigorous yellow pines, suitable for seed trees, should be left in greater numbers to take the place of diseased black jacks removed, to maintain better forest conditions, and to furnish abundant seed for the restoration of the stand. Small heavily infected black jacks should be marked wherever it is possible to have them cut under the sanitation clause of the timber-sale contract, or where there is a market for small material, such as stulls, mine props, ties, poles, posts, and pickets.

Forest officers in charge of marking on mistletoe-infected timber-sale areas should study carefully the possibilities of increasing the number of healthy trees in the remaining stand. The pruning of infected limbs from small trees at the time of marking presents a practical means of eliminating light limb infections and at the same time increasing the number of healthy trees. Occasionally there are trees in a stand that are lightly infected on a low branch within reach of the ground. Mistletoe-infected reproduction and young timber below merchantable size should also be freed from the disease either through cutting the seedlings and saplings or by lopping off the infected branches. Such measures may be impracticable except on timber sale areas and in some cases the extra labor and expense involved may prove prohibitive.

The areas of mistletoe infection should be located and mapped as a prerequisite to an efficient control campaign. The degree of injury

and the amount of infection should also be recorded. Weir[13] has suggested that this could easily be done by timber-survey parties in connection with their regular mapping and cruising work. Such tangible records of mistletoe infections would be invaluable to forest officers in showing just where diseased stands are located, in order that an attempt be made to exploit stands of seriously diseased timber as rapidly as possible.

The advent of a large commercial timber-sale operation should not be awaited before undertaking mistletoe-control work. Small ranger sales and even the issuance of free-use permits would materially assist in the reduction of severe infections. Although in many instances the large lumbering operation is more economical than the small one, the latter can render a definite service in improving the hygienic condition of the forest through removing more or less isolated infections which are too small to be exploited in a large operation. The products of the small operation are not marketed in such highly finished or specialized form as are many of the products of the large operation. In the case of a small lumbering operation mistletoe-infected trees will, in almost every case, be as well adapted to the desired uses as the products of healthy trees.

The problem of the control of mistletoe assumes two quite different aspects, depending upon the degree of infection on a given area. Silvicultural systems of regeneration should provide for the eradication of the mistletoe from the stand as one of the most necessary results to be accomplished. On areas adequately stocked with advance reproduction all infected trees should be cut. On the other hand, on areas of light to moderate infection special emphasis should be laid upon the need of leaving all healthy trees possible, even if they belong to the "yellow-pine" class, in order to insure as good a condition of the forest cover and seed production as possible. Where the injury is not very serious the marking rules should call for the removal of all mistletoe-infected trees possible without breaking up the continuity of the stand or materially interfering with the silvicultural system of management adopted for the area. Lightly infected areas should be marked in such a manner that, with supplemental pruning at the time of marking, the stand would be practically free of infection. Lightly infected black jacks and transition trees on areas bearing no advance reproduction should not be cut when otherwise thrifty and sound, except where thinnings are desirable to obtain increased growth or where reproduction is established. Such thinnings, however, may be somewhat heavier than in uninfected stands; but in lightly infected black-jack stands where reproduction is not established vigorously growing and thrifty trees should not be radically sacrificed.

[13] Weir, James R. Some Suggestions on the Control of Mistletoe in the National Forests of the Northwest. Forestry Quarterly, 14: 567–577, 1916.

Lightly infected yellow pines should be left when uninfected trees or lightly infected black jacks are not available for seed and protection.

Moderately infected trees should always be marked for cutting, except where there are no other trees available to leave as seed trees. Mistletoe can not in all cases be eliminated in one cutting without too great a sacrifice of silvicultural requirements. Moderately infected trees should not be left for seed on lightly infected areas if healthy trees are available within 100 yards. This, however, applies to large areas rather than to small openings or small areas which have a chance to seed in from surrounding trees and where infection might be removed completely without opening the forest too extensively. Moderately infected trees should be left for soil-protection purposes only on the most adverse sites, where their need for this purpose is clearly evident.

Areas of heavy infection on which the injury from mistletoe is alarming should receive special attention and should be treated from the standpoint of the sanitation of the forest. Areas where the entire stand is too heavily infected to permit carrying out sanitation measures without material interference with the silvicultural requirements of the forest should be marked for clear cutting. In practice such a condition will seldom be encountered. The largest possible number of small trees infected with mistletoe should be utilized. Areas of unmerchantable reproduction infected with mistletoe should be freed of the disease either through cutting the diseased seedlings and saplings or by pruning off infected branches. In certain cases it would be desirable for the owner of the forest to devote special funds for mistletoe-control projects, as is done in the case of serious insect infestations.

While the areas infected with mistletoe to such an extent that diseased trees must be left or the stand practically clear cut, are not extensive, areas will probably be found on which forest planting to fill in blank growing spaces will be desirable following operations approaching a clear cutting under a mistletoe-control project. It may also be advisable from the standpoint of economy to clear-cut and plant certain limited areas of heavy infection. A definite policy of mistletoe control should be adopted for mistletoe-infected areas to be cut over by timber sales. Necessary funds should be provided to complete the cleaning of the areas after the operator has removed all of the diseased trees which he can be required to take under the agreement.

Forests in the vicinity of nurseries and planting areas should present unusually healthy conditions. It should be remembered that healthy trees can not be grown in an insanitary environment. All mistletoe infection in the vicinity of forest nurseries and planting areas should therefore be removed.

When a proposed timber-sale area contains a considerable amount of mistletoe, a special mistletoe sanitation clause should be inserted in the contract, containing the stipulation that all heavily infected trees, whether merchantable or unmerchantable, and certain other moderately infected trees will be marked for cutting. If the amount of unmerchantable infected timber is sufficient to affect the stumpage price materially, this factor should be fully taken into consideration and due allowance made for it in the stumpage appraisal.

In control work on those areas where both mistletoe and insects are present, it would be advisable to combine the eradication of both pests where the commercial value of the stand justifies such measures. Infestations of secondary bark borers have occasionally been found and reported with or immediately following mistletoe infection.[14] It is believed that certain of these insects even show a slight preference for trees infected with mistletoe. The attack of trees weakened by the mistletoe often hastens their death, or in the case of dead trees the work of the borers hastens deterioration. The control of such combined infection and infestations by eliminating the weakened trees would tend to control both mistletoe and insects, and thus hasten the realization of the ideal—a productive, thrifty, and healthy forest.

The western yellow pine mistletoe probably has few natural enemies which can contribute toward its control. During the course of the studies reported in the preceding pages, a spittle insect (*Clastoptera obtusa*)[15] was very frequently found within masses of spittle on the mistletoe plants. The work of the insect in controlling the mistletoe is probably of little practical importance. However, since the insect subsists on the juices of the mistletoe, it must tend to weaken the mistletoe to a certain extent, especially in cases of severe infestations.

Through a proper realization and appreciation of the necessity for adequate control measures and their adoption on all cutting areas where the amount of mistletoe infection is relatively great, a very good beginning can be made toward the eradication of the pest through the more or less gradual process of elimination.

SUMMARY.

Western yellow pine is subject to severe injury by mistletoe (*Razoumofskya cryptopoda*). The injury to the forest caused by the insidious and destructive action of this pest results in serious losses of western yellow pine and presents one of the most important silvicultural problems in the Southwest.

[14] Hopping, Ralph. Insect Infestation in Relation to Injury, Fungi, and Mistletoe. Manuscript report. February 24, 1915.

[15] Determined by E. H. Gibson, Scientific Assistant, Bureau of Entomology, U. S. Department of Agriculture.

Mistletoe infection causes a marked decrease in the rate of growth of the host, which continues until the virulent parasite ultimately causes the death of the tree. The rate of decrease varies directly with the degree of infection from little or no decrease in the growth of lightly infected trees to a very marked falling off in the current growth of heavily infected trees. Many trees are killed annually by this pest alone or in conjunction with other causes, such as insect infestations or porcupine injury.

The decrease in the rate of diameter and height growth and the consequent current increment of trees infected with mistletoe are accompanied by a reduction of the leaf surface of the host.

Trees of all age classes are subject to mistletoe infection, provided the seeds of the parasite fall on parts of the tree which are not protected by the bark. Young seedlings and saplings usually die comparatively soon after becoming severely infected, while older trees may remain alive for a much longer time.

The quantity and quality of the seed produced by trees infected with mistletoe is below that of normal, healthy trees. Heavily infected trees are practically worthless for seed production and should not be left as seed trees.

The most practical method of controlling mistletoe is to remove the infected trees while cutting operations are in progress. All heavily infected trees should be marked for cutting. Moderately infected trees should be marked for cutting except where others are not available for seed trees. On areas of light to moderate infection the marking rules should require the removal of all mistletoe-infected trees possible without breaking up the continuity of the stand or materially interfering with the silvicultural requirements of the forest. Exceptional care should be taken to leave as heavy a stand of healthy trees as possible in order to compensate for the removal of diseased trees and to maintain better forest conditions.

Areas on which the entire stand is too heavily infected with mistletoe to permit adequate sanitation measures without very material interference with the silvicultural requirements of the forest should be marked for clear cutting under a mistletoe-control project. Although in actual practice such a condition will seldom be encountered, relatively small areas will probably be found on which forest planting may be desirable.

When proposed timber-sale areas contain a great amount of mistletoe, a sanitation clause should be inserted in the timber-sale contract requiring the cutting of all heavily infected trees, whether merchantable or unmerchantable, and certain other moderately infected trees which may be marked.

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